Analysis on the daily courses of water potential of nine woody species from Cerrado vegetation during wet season

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Abstract   The water potential (Ψ) daily courses of 9 woody species from Cerrado vegetation in different weather conditions during wet season were observed and analyzed. The adjusting strategies of 9 species could be divided into 3 groups according to Cluster Analysis and based on the data observed on the January 18, March 20 and April 6. The Ψ values of the first group, which included 2 species, were maintained at the higher level consistently. The Ψ values of the second group, which included 5 species, were intermediate level. The Ψ values of the third group, which included 2 species, were kept in the lower level. The Ψ values of all species always kept pace with the weather condition, especially water condition. During the clear day only one Ψ value peak for all species occurred at midday (12:30-13:30). When the overcast or raining occurred for a short period, the fluctuation of Ψ values would appear after about 15-30 min responding to the change of weather condition. Even in the same group under the same external circumstance, there was a clear variation of the leaf Ψ values among different species, which showed that the strategy diversity for plant to balance water relation. From January to April, the Ψ values of 9 species reduced in response to the drought condition. The species with the lower values of water saturation deficiency at turgid loss point (W_{sdtlp}), the osmotic potential at saturation (π_{sat}), the osmotic potential at turgid lose point (π_{tlp}) or lower predawn water potential (Ψ_{pd}) usually had the lower Ψ values at midday. The mechanism of water balance controlled by many systems has been assumed.

Key words: Wet season, Water balance strategy, Osmotic potential, Water potential, Woody species

Introduction

As the concept of water potential (Ψ) was introduced by Saltyer (1967), there were some arguments on it among some physiologist. Some physiologists opposed it because they believed Ψ value might not be the best parameter for describing physiological processes. However, this concept has been accepted and used by most plant physiologists for many years (Kramer 1988; Schulze *et al.* 1988; Passioura 1988; Boyer 1989).

According to our experience (Prado *et al.* 1994, 1995), we believed that the leaf or shoot water potential played an important role in the water movement, physiology, metabolism in plant body and the

soil-plant system. The gradient of the water potential had been considered as the driving force for water transport in the plant body (Schulze *et al.* 1988; Boyer 1989). Water movement from soil to leaves could be regarded as occurring along a gradient of decreasing water potential produced by loss of water in transpiration (Kozlowski *et al.*1991). The water potential has been used to describe the water status in plant because it is based on the free energy status of water and physical basis of the thermodynamic (Kramer 1988). Many experiments showed that the water stress would occur during sunny weather, midday water deficits, even in the moist soil. (Laker *et al.* 1987; Tazaki *et al.* 1980; Kramer 1988). Water stress usually affects the normal plant metabolism and unavoidably leads to inhibition of photosynthesis and stomata conductance (Prado *et al.* 1994; Kozlowski *et al.* 1991). Plant water potential (Ψ) at given status of hydration is decided by the osmotic water potential

(π) and the pressure potential (Ψ_p), ($\Psi = \pi + \Psi_p$). Plant water-storing capacity is dependent on modulus of elasticity (ε) of cell wall (Larcher 1995). Therefore, water potential (Ψ) values are influenced by external conditions and other water parameters.

Cerrado vegetation, a kind of neotropical savanna, covers about 1.8×10^6 km² and shows different physiognomic types, and is an important kind of vegetation in Brazil. The distinct wet and dry seasons occur repeatedly every year in this area. The water relation balance ability for plant to survivor plays a very important role under the daily water stress. However, the research work on the water relation parameters of woody plant in Cerrado vegetation was rare (Prado et al. 1994). The water potential daily courses and strategies for woody species in response to the water stress during a day have been unknown.

In this paper, 9 important component species were chosen to measure daily courses of leaf water potential (Ψ) under different weather conditions in the wet season. In addition, the osmotic water potential (π) and modulus of elasticity (ε) of cell wall of 9 species also were measured in January. The aims were to know characteristics of water potential adjustment of Cerrado woody species.

Methods and materials

The studies were carried out in the Federal University of Sao Carlos in Brazil. The samples were from the Cerrado reservoir located in the north area of Sao Carlos city ($22°00'$-$22°$ $30'$ S and $47°$ $30'$- $48°$ $00'$ W). The mean temperature is 18.1 °C during the coldest month and 23.1 °C during the hottest month. The mean precipitation is 24.10 mm during the driest month (July) and 285.95 mm during the wettest month (January), (Tolentino 1976?). From January to April the rainfall increasingly decreased. In experiment year, the precipitation in January is 286 mm, 222 mm in February, 190 mm in March and 72 mm in April, respectively.

Three kinds of daily course of water potential were observed. The first daily course was a clear day on April 6 (the end of wet season). The second daily course was a clear day with rain for 21 min and overcast for 4 short times (10-30 min) on March 20 (transition between wet and dry season). The third daily course was clear day with rain for 15 min and overcast for 4 short times (10-90 min) on January 18, (typical wet season). The reasons for this were that they could represent the basic weather condition in wet season.

The typical indigenous species *Bahuinia holophylla, Campomanesia aromatica, Didymoppanax vinosum erythroxylon sp., Piptocarpha rotundifolia,*

Roupala montana, Stryphnodendron obovatum and *Tibouchina stenocarp,* which were played important roles in the components of Cerrado vegetation, were chosen. The one individual of each species, growing healthily, at adult age, was selected and marked in the area of 100 m² in order to get samples in the same condition. The branchlets or leaves fully expanded were cut from individual and water potentials were measured immediately in the field condition. The experiments were carried out from 7:00 to 18:00. The interval of each measurement was about 1-2 h. As soon as the sap of the leaf or branchlet went out as the chamber pressure increased, the pressure gauge would be read. Usually measurements were repeated 3 times for one species in order to reduce the errors.

Employing small branches or leaves were covered with plastic film, the pressure-volume curves (p/v, $1/\pi$ vs. W_{sd}) of 9 woody species in January were derived from the Santa Barbara Soil Moisture Pressure Chamber, model 3005, made in USA. From the p/v curves, the osmotic potential at saturation (π_{sat}), the osmotic potential at turgid lose point (π_{tlp}), the modulus of elasticity (ε), and the water saturation deficit at turgid loss point (W_{sdtlp}) were derived. For each sample, π_{sat} and π_{tlp} were estimated via linear regression of data in the straight part of the p/v curves. The ε and W_{sd} were calculated by following equations:

$$\varepsilon = \Delta p / (\Delta V/V)$$

$$W_{sat} = (F_{WAP} + T_{SE}) - D_W$$

$$W_{act} = W_{sat} - S_E$$

$$W_{sd} = [(W_{sat} - W_{act})/W_{sat}] \times 100\%$$

Where

Δp: change of turgid pressure (MPa); ΔV: change of leaf tissue volume connected with Δp (mL);

V: total leaf tissue volume (mL); W_{sat}: water weight of leaf in saturation condition (g);

F_{WAP}: leaf fresh weight after pressure (g); T_{SE}: total sap extract (g); S_E : Sap extract (g);

D_W: leaf dry weight (g); W_{act}: actual leaf water weight (g);

W_{sd}: water saturation deficit (%). Each parameter is the mean value after measuring 3 times.

The hierarchical dendrogram of the patterns of the Ψ value of daily courses among 9 species was been built up after the Cluster Analysis with Complete linkage and Euclidean Distances. The process of Cluster Analysis was carried out by soft-ware (Statistica for windows, Release 4.3®, Statsoft Inc. 1993).

Results and discussion

The three kinds of daily courses of water potential (Ψ) of 9 woody species

The daily courses of water potential in response to the clear day on April 6 were shown in Fig.1. In response to the water stress at midday, the Ψ values of

group 1 went down about -1.1 MPa. The Ψ values of the group 2 were the intermediate, range from -1.3 to -2.0 MPa. The Ψ values of group 3 decreased largely, the range from -2.0 to -2.7 MPa. Although the weather condition was stable, the Ψ value fluctuation of every species was different.
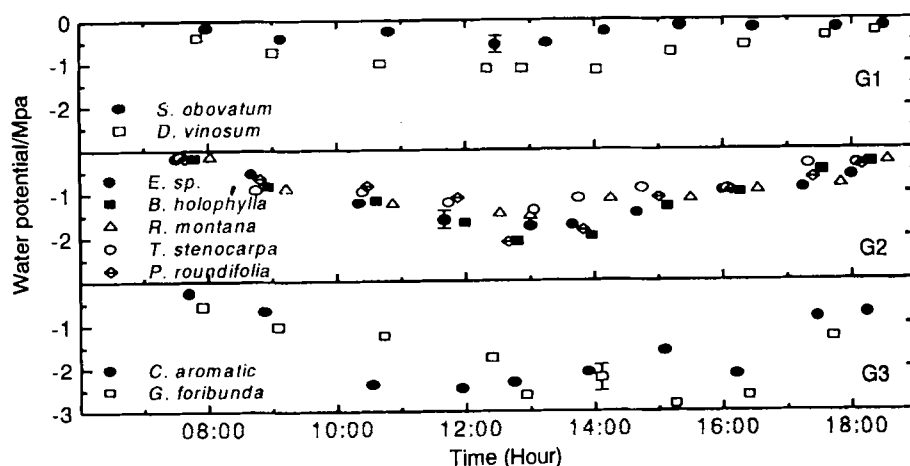

Fig.1. The daily course of water potential (Ψ) of 9 species on April 6

G 1, G 2, G 3: group1, group2, group3; -: clear

The pattern of Ψ value of daily course of 9 species was a response to the water stress with 4 cloudy periods (10-30 min) and raining of 21 min on the March 20 (Fig.2). From 7:00 to 11:30, as the temperature rose, the Ψ values of 9 species were going down to the lowest peak. The lowest Ψ values for most species appeared at 13:00. The lowest Ψ value of group 1, group 2 and group 3 was -1.5 MPa, -2.0 MPa, and -2.2 MPa respectively. In addition, from

11:30 to 11: 45, 11:50 to 12:00, 13:50 to 14:15 and 15:20 to 15:30, there were alternate 4 short cloudy periods with the corresponding a little rises of Ψ values correspondingly. From 14:35 to 14:56 it was raining, the Ψ values of 9 species increased a lot and reached the second higher peak. Usually, the fluctuation of the Ψ values of most species would lag 15-30 min after the alteration of the weather condition.
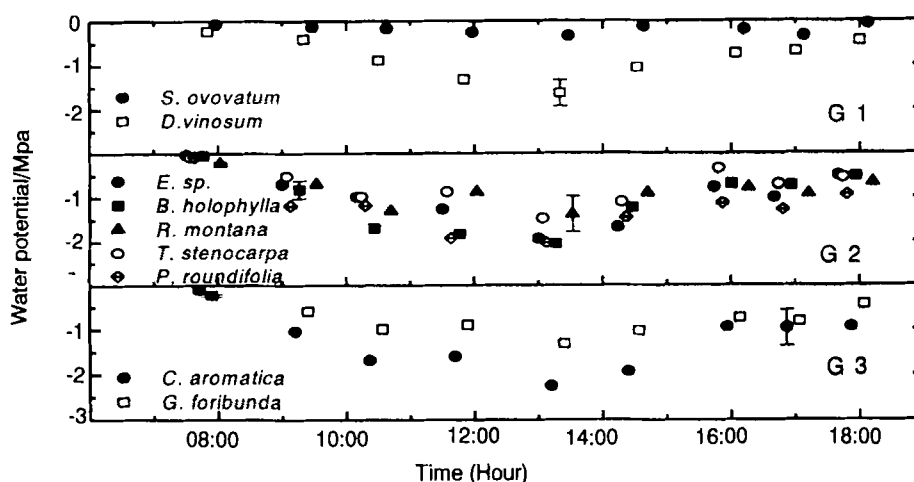

Fig.2. The daily course of water potential (Ψ) of 9 species on March 20

G 1, G 2, G 3: group1, group2, group3; -: clear; #: overcast; ////: raining

January 18, during the wettest month, was also a clear day with overcast for 4 short times (25-80 min) and raining 15 min. The Ψ value patterns of 9 species were shown in Fig.3. From 7:00 to 11:30, it was clear, Ψ values of 9 species decreased as the temperature increased. It was cloudy from 11:30 to 12:00, 12:40 to 14:00 and 14:30 to 14:55, the water potential of 9 species increased a little and maintained the lower level. The Ψ low peaks for most

species appeared at 12:30. The lowest Ψ values of group 1, group 2 and group 3 were -1.0 MPa, -1.4 MPa and -2.0 MPa, respectively. It rained at 15:00 for 15 min, the Ψ values of 9 species increased largely. It was clear again at 15:30 for 30 min, the Ψ values of 9 species reached the lowest Ψ values of three groups for -0.5, -0.8 and -0.8 MPa, respectively. It was overcast from 16:30 to 18:30, the water potential increased again and maintained higher level.
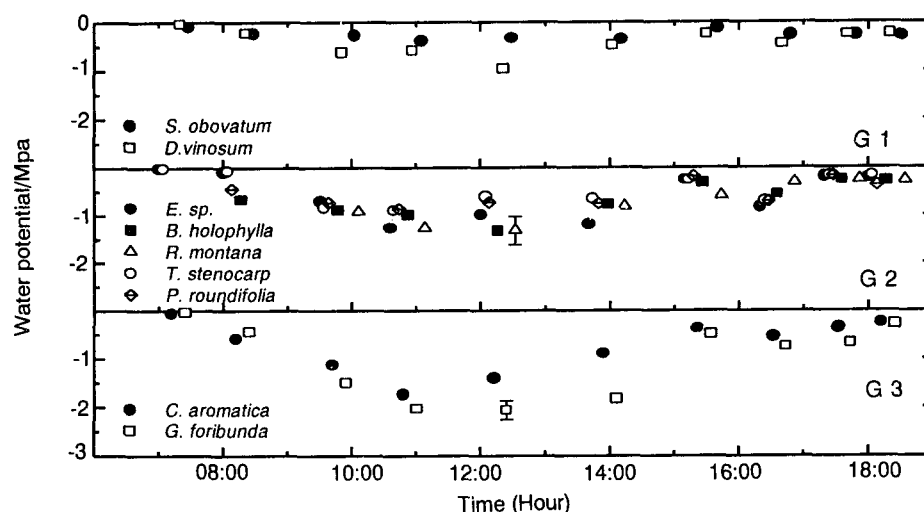

Fig.3. The daily course of water potential (Ψ) of 9 species on January 18

G 1, G 2, G 3: group1, group2, group3;   ·: clear;   #: overcast;   ////: raining

Compared and analyzed the 3 kinds of the water potential daily courses, the regulations could be known.

a). The mechanisms for plants to adapt the water stress were different among 9 species. Some species performed the less sensitive to the water stress. And some of them were more sensitive. The lag time for the Ψ value change of each species after the alternation of the weather was different (Fig.1-3). Even in the stable weather condition, the Ψ value fluctuations for most species were various.

b). The daily courses of Ψ values always kept the pace with the water condition in the field (Larcher 1995; Kozlowski *et al.* 1991). In the clear day, the solar radiation was able to cause a lot transpiration, which led Ψ value to decreasing rapidly and reached the lowest point at midday, even in the moist soil. When the water conditions were improved (raining or cloudy), the Ψ values would increase gradually (Kozlowski *et al.* 1991). As soon as overcast appeared, the Ψ values rose. A short time rain usually could alleviate the water stress immediately. The intensity of rainfall or cloud was closely related with the alternation of Ψ values. However, as soon as the raining or overcast was over, the Ψ values would decrease rapidly again. Regardless overcast or little rainfall,

this kind of relaxation of water stress was transient because they alleviated water stress just through reducing transpiration or added water on the surface of plant. Therefore it is reasonable for us to assume that the Ψ values could represent the instant water status in the plant.

c). In the moist soil, the water absorption was controlled largely by the rate of transpiration. But in the drying soil it was controlled by the difference of water potential between root and soil. Lower soil water potential increased resistance in water movement toward roots from drying soil (Kramer 1983). Therefore, the Ψ values of 9 species would go down, as the soil became increasing drought from January to April in order to strengthen the ability of absorbing the water from more drought soil. The average Ψ values in April were lower than those in March and January, and this situation was stable and didn't change easily.

The cluster analysis on the strategies of water potential adjustment of 9 species

Although the mechanism for different species to balance water relation was various in Cerrado field condition, daily course patterns of water potential were similar among 9 species. The strategies of 9

woody species from Cerrado to balance water potential could be divided in to 3 groups (G 1, G 2, G 3) by

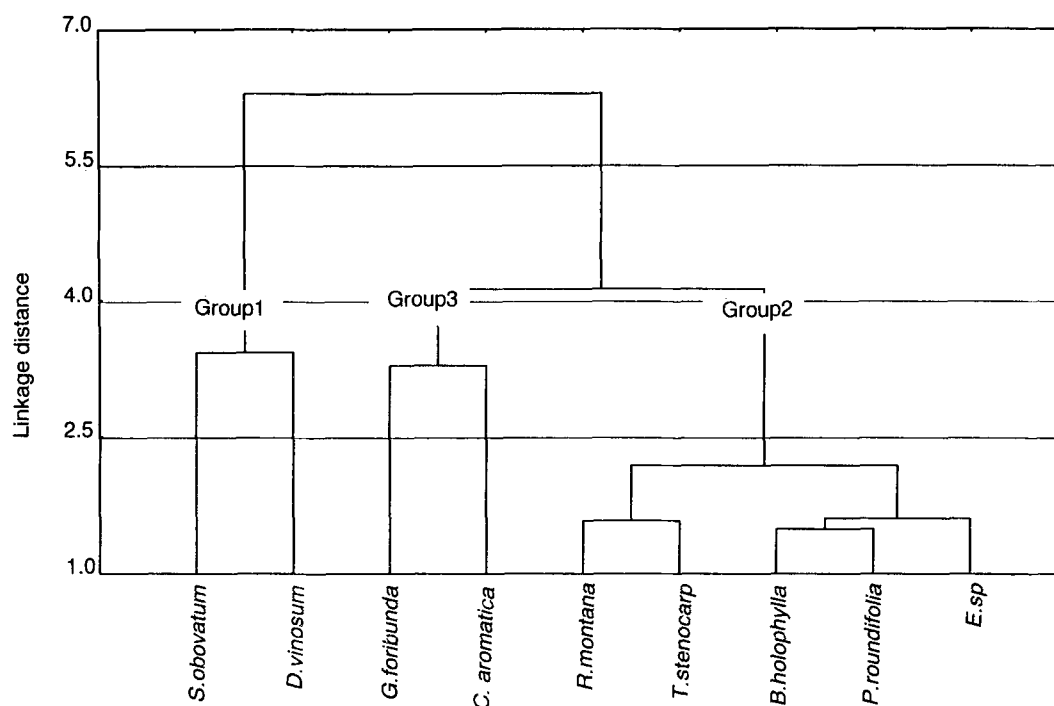the Cluster Analysis when the linkage distance was 4.0. (Fig.4).

Fig. 4. The tree diagram for 9 species on water potential (Ψ)

After Cluster Analysis with Complete linkage and Euclidean Distances, the strategies of 9 woody species from Cerrado to balance water potential are divided to be 3 groups when the linkage distance is 4.0.

The first group included *S. obovatum*, *D. vinosum*, which maintained their water potential at higher level in January, March and April (Fig.1-3). The second group included 5 species, *E. sp., B. holophylla, R. montana, T. stenocarpa* and *P. roundifolia* which maintained at intermediate level on the Ψ values in January, March and April (Fig.1-3). The third group included *C. aromatica* and *G. foribunda*, which could reduced their Ψ values to be very low level responding to the daily water stress in January, March and April (Fig.1-3). It was clear that the results of classification were objective and tallied with the fact. The similarity in the same group in response to changing external environmental conditions could be presumably considered to be the congenial evolution in the mechanism for plant to adapt environmental stress (Rundel 1991).

The relations among the concerned water relation parameters

The osmotic potential at saturation (π_{sat}), osmotic potential at turgid loss point (π_{tlp}), the lowest water potential at midday (Ψ_j), modulus of elasticity (ε), water saturation deficit at turgid loss point (W_{sdtlp}), and the predawn water potential (Ψ_{pd}) of 9 woody

species with standard error (S_e) in January were shown in Table 1. The range of π_{sat} was from -1.32 (*T. stenocarpa*) to -2.46 MPa (*R. montana*). The ε values changed from 8.03 (*B. holophylla*) to 23.92 MPa (*C. aromatica*). The range of the W_{sdtlp} was from 3.70% (*R. sp.*) to 15.99% (*D. vinosum*).

Higher Ψ_{pd} values indicated that all species were well hydrated in January. The species with the lower W_{sdtlp} values or with the lower Ψ_{pd} values usually had the lower Ψ values during the whole day (*C. aromatic and G. foribunda*) (Fig. 1-3; Table.1). The Ψ values of species of group 1 were lower than those of group 2 and group 3 in January, March and April.

On the other hand, among the different water parameters of each species, the values of π_{sat} were in proportion to that of π_{tlp}. The species with lower values of π_{sat} usually had lower W_{sdtlp}. The species with the higher π_{sat} and π_{tlp} values usually had the lower ε value. The Ψ_j values of each species were never lower than its π_{sat} values. This result showed that the water status of plant was controlled by many systems (Schulze *et al.* 1988), and the mechanisms for Cerrado species to balance water relation were diverse.

Table 1. Water relation parameters of 9 woody species with standard error (S_e) in January

No.	Species	π_{sat} /MPa	S_e (π_{sat})	π_{tlp} /MPa	S_e (π_{tlp})	Ψ_j /MPa	S_e (Ψ_j)	ε /MPa	S_e (ε)	W_{sdtlp} (%)	S_e (W_{sdtlp})	Ψ_{pd} /MPa	S_e (Ψ_{pd})
1	*Bahuinia holophylla*	-1.52	0.01	-1.98	0.02	-1.33	0.13	8.03	0.58	14.62	12.36	-0.06	0.000
2	*Campomanesia aromatica*	-2.31	0.01	-2.70	0.07	-1.40	0.12	23.92	0.45	6.26	5.15	-0.12	0.004
3	*Didymopanax vinosum*	-1.95	0.09	-2.35	0.04	-0.95	0.06	14.81	1.65	15.99	9.84	-0.07	0.004
4	*Erythroxylon sp.*	-2.35	0.04	-2.85	0.04	-1.20	0.08	21.93	0.38	11.58	8.58	-0.10	0.007
5	*Gochnatia floribunda*	-2.07	0.03	-2.75	0.02	-2.07	0.07	11.76	0.65	5.87	4.04	-0.08	0.000
6	*Piptocarpha rotundifolia*	-1.40	0.06	-1.75	0.04	-0.75	0.08	10.86	0.53	10.23	7.70	-0.05	0.000
7	*Roupala montana.*	-2.46	0.01	-2.78	0.02	-1.33	0.08	20.51	1.07	3.70	2.49	-0.06	0.004
8	*Stryphnodendron obovatum*	-1.99	0.00	-2.50	0.07	-0.33	0.04	14.44	1.02	15.42	10.74	-0.06	0.004
9	*Tibouchina stenocarpa*	-1.32	0.04	-1.69	0.01	-0.65	0.06	9.38	0.59	10.05	7.12	-0.06	0.007
	Mean	-2.09	0.03	-2.60	0.07	-1.11	0.08	19.66	0.54	10.27	7.23	-0.07	0.003

Notes: π_{sat} : osmotic potential at saturation; π_{tlp}: osmotic potential at turgid loss point; Ψ_j : the lowest water potential at midday in January; ε: modulus of elasticity; W_{sdtlp}: water saturation deficiency at turgid loss point; Ψ_{pd}: the predawn water potential. The each parameter is the mean value after measuring 3 times

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